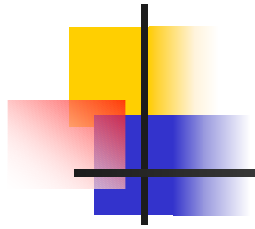# Human Exposure Modeling:
Concepts, Methods, and Tools

Janet Burke
Stephen Graham
US EPA ORD
National Exposure Research Laboratory
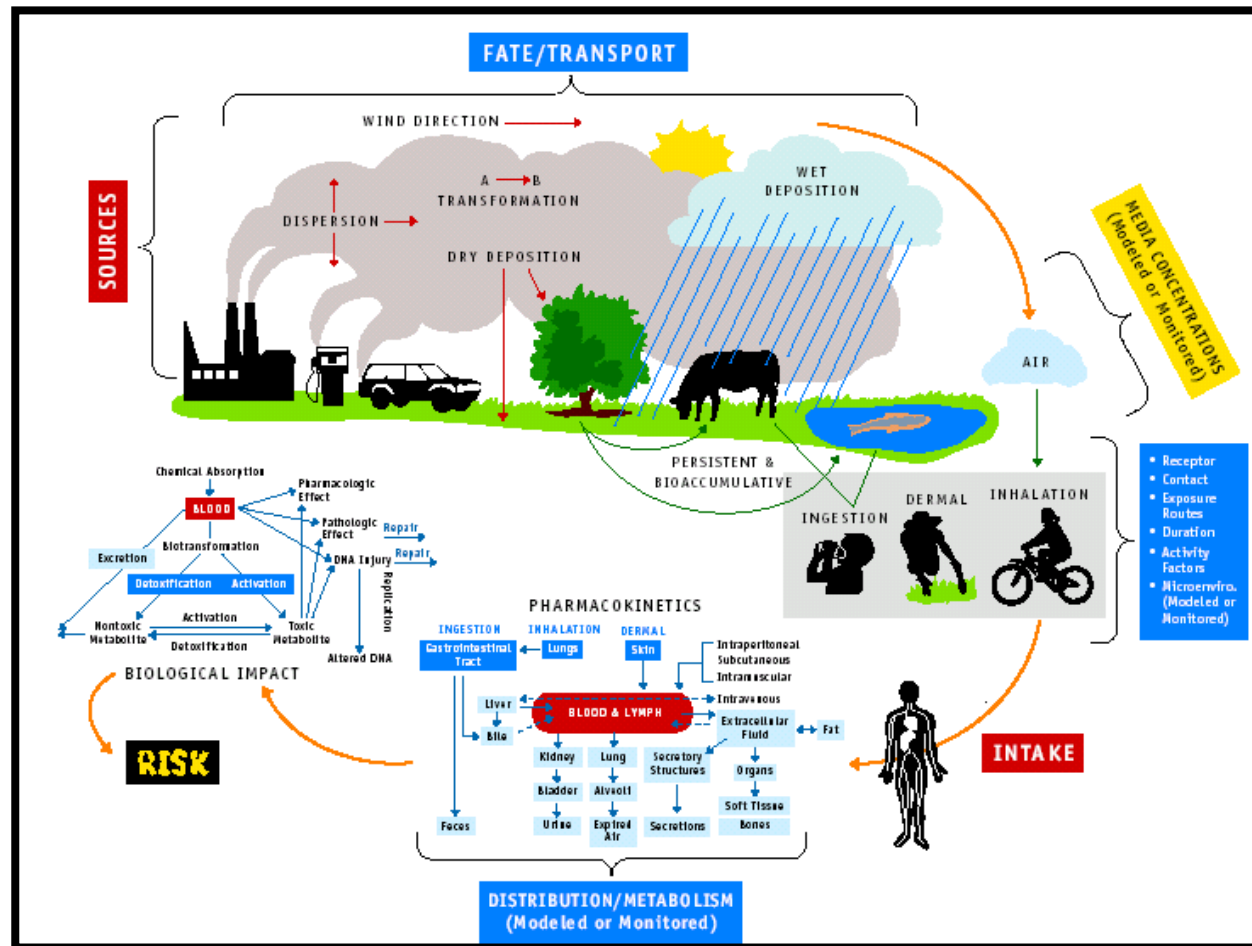
Ted Palma
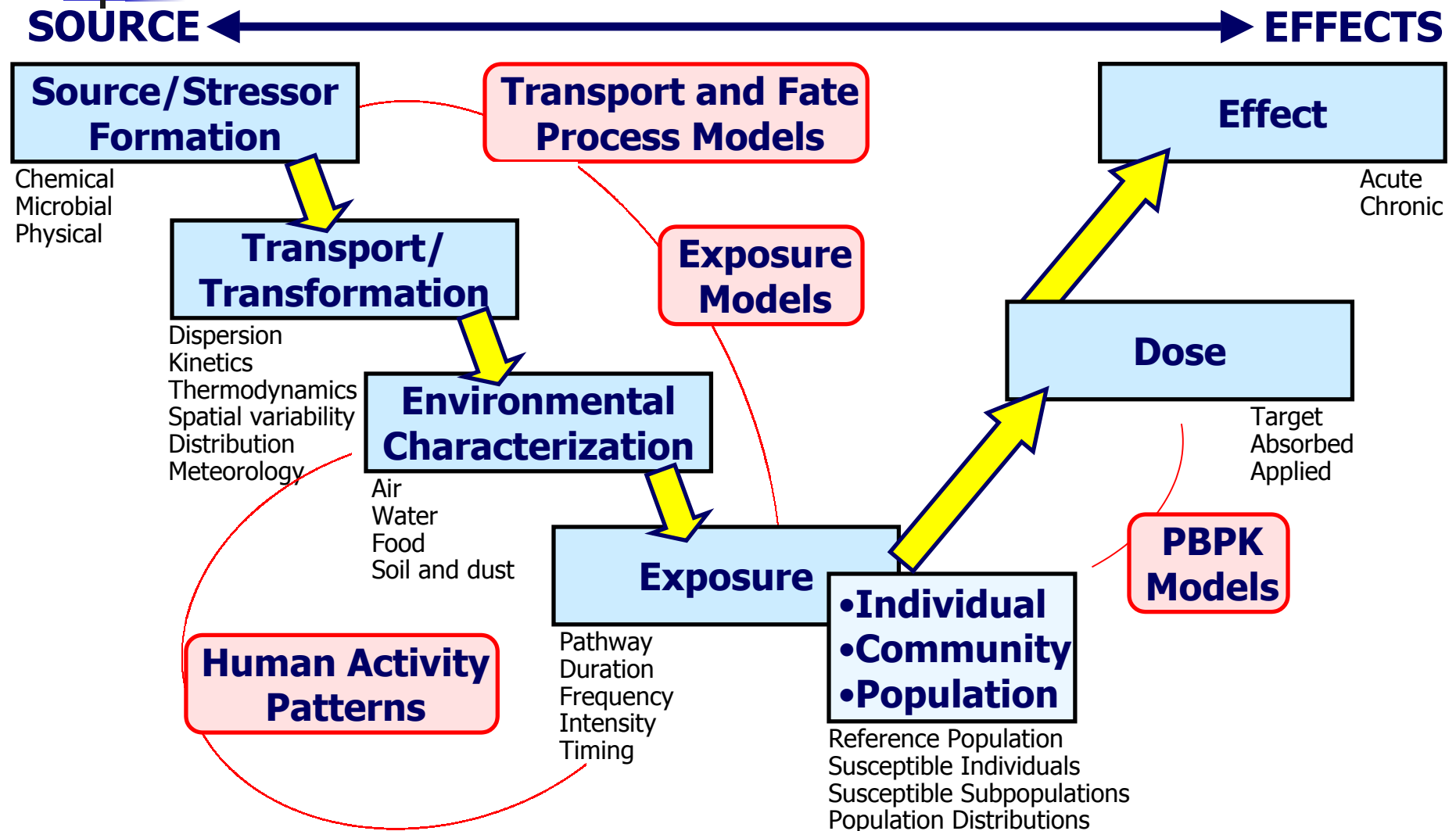US EPA OAR
Office of Air Quality Planning and Standards

Outline

- **Exposure Modeling Concepts**
  - Source-to-effects
  - Scale (national → neighborhood)
  - Type of assessment (screening level → detailed)
  - Metrics
- **Exposure Modeling Methods**
  - Population exposures → Stochastic/Probabilistic
  - Time series → Human activity patterns
  - Exposure Pathways
- **Exposure Modeling Tools**
  - Human Activity Database → CHAD
  - Inhalation only → HAPEM, APEX, HEM
  - Multipathway → TRIM, SHEDS
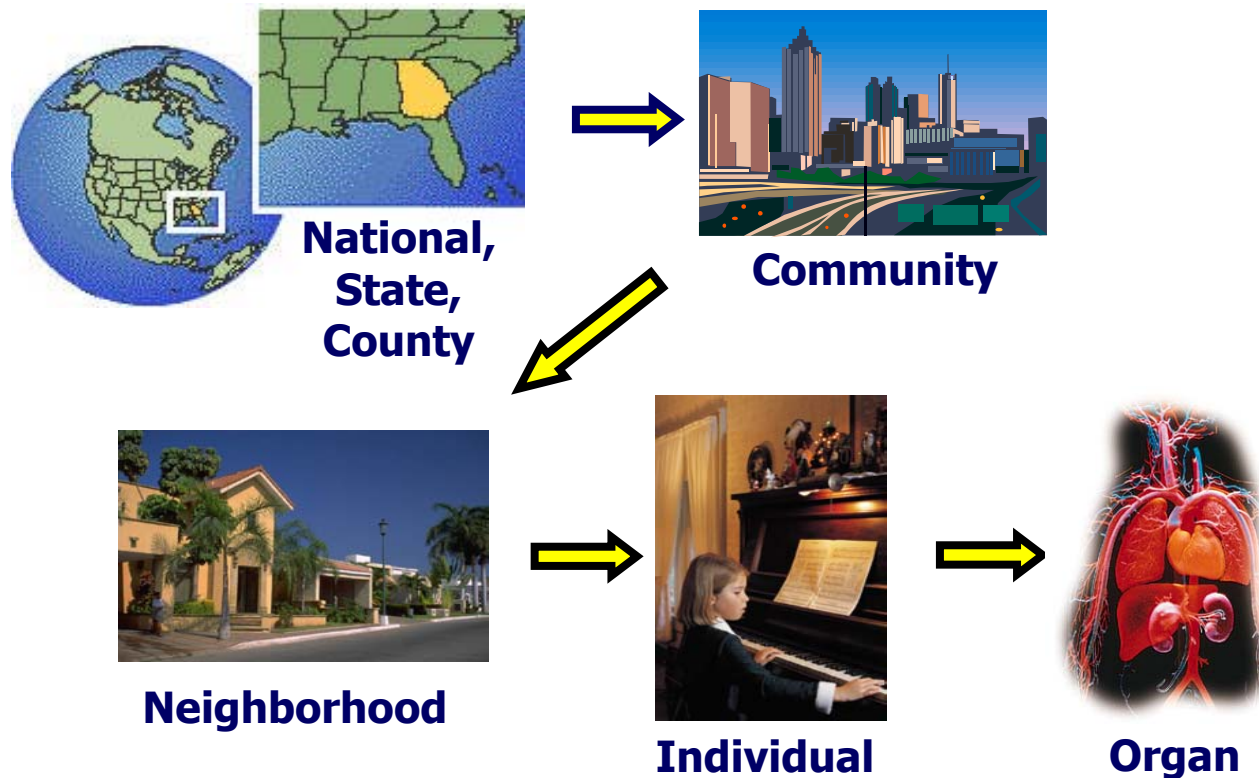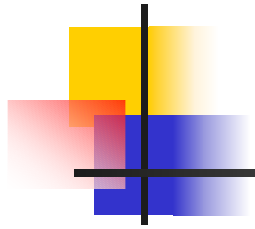
Exposure Modeling Concepts

Exposure Modeling Concepts

SOURCE ←———————————————————→ **EFFECTS**

Source/Stressor Formation

Chemical
Microbial
Physical

Transport and Fate Process Models

Effect

Acute
Chronic

Transport/ Transformation

Dispersion
Kinetics
Thermodynamics
Spatial variability
Distribution
Meteorology

Exposure Models

Dose

Target
Absorbed
Applied

Environmental Characterization

Air
Water
Food
Soil and dust

Exposure

Pathway
Duration
Frequency
Intensity
Timing

**•Individual
•Community
•Population**

Reference Population
Susceptible Individuals
Susceptible Subpopulations
Population Distributions

PBPK Models

Human Activity Patterns

Exposure Modeling Concepts

- Scale of interest consistent with model

National, State, County → Community

Community → Neighborhood

Neighborhood → Individual → Organ

Exposure Modeling Concepts

- Complexity of model consistent with type of assessment
  - Screening level → identify pollutants with potential for high exposures
  - Detailed exposure assessment for a pollutant → more accurately assess exposure levels
  - Additional data requirements as complexity of model increases
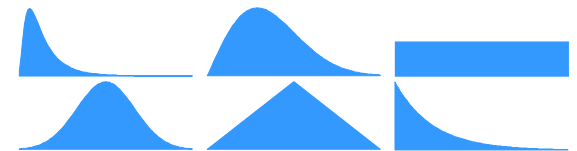
Exposure Modeling Concepts

- Exposure/dose metric consistent with health effect of concern
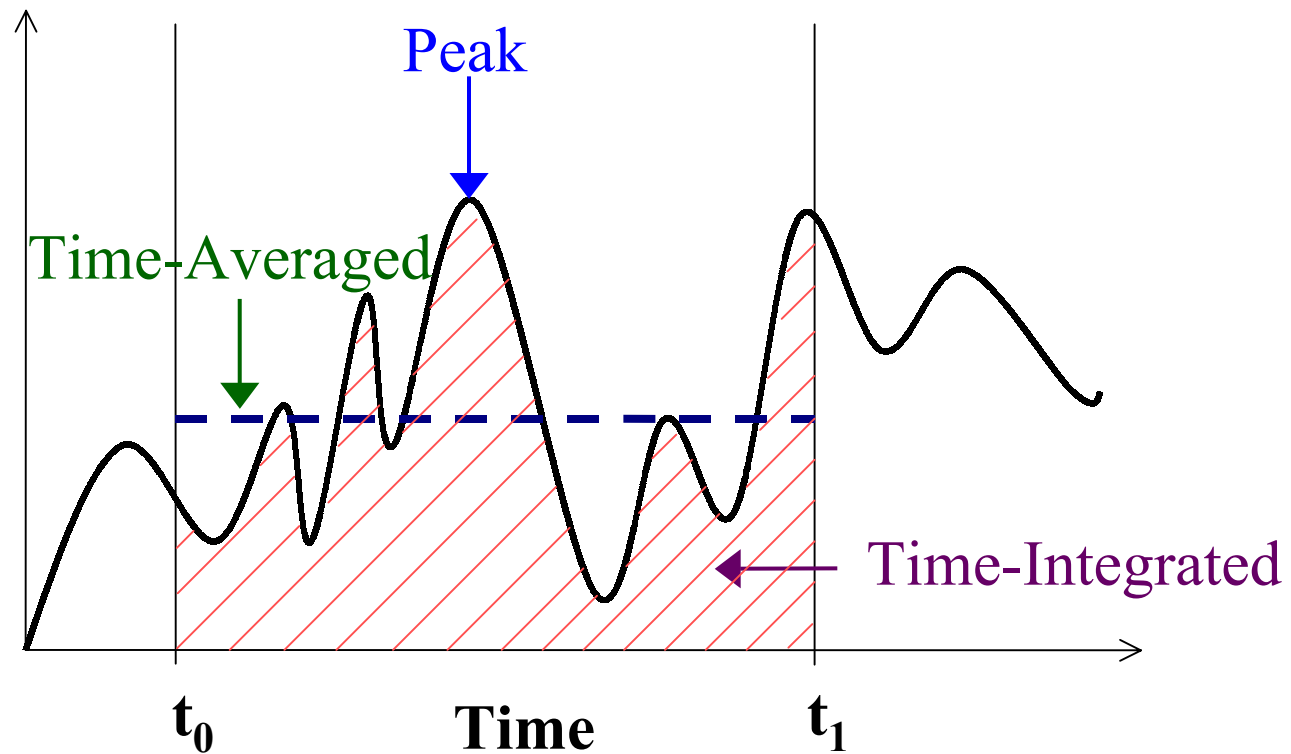
Exposure Modeling Methods

- Statistical models
    - Developed using empirical data from personal monitoring studies
    - Example: Regression equations that explain measured exposures

- Deterministic models
    - Based on known or assumed physical relationships
    - Example: Air quality models

- Stochastic models
    - Input data are distributions, not single value
    - Input distributions characterize variability/uncertainty in the data
    - Use Monte Carlo or other random sampling techniques
   - Produces output distributions (variability/uncertainty)

Exposure Modeling Methods

- **EPA Exposure Models**
  - Use similar methods:
    - Population distribution of exposures estimated using stochastic modeling
    - Microenvironmental modeling approach
    - Time series approach → Human activity patterns
  - Inhalation pathway primary focus
  - Multipathway pollutants require additional complexity
  - Models available for different objectives:
    - Screening-level assessment → Detailed assessment

Exposure Modeling Methods

- ## Population exposures

  - US Census data used to generate simulation population that demographically represents population of interest
    - Age
    - Gender
    - Race
    - Employment status

  - Simulate exposure for individuals → combine for estimates of population distribution

9   0   9   18 Kilometers
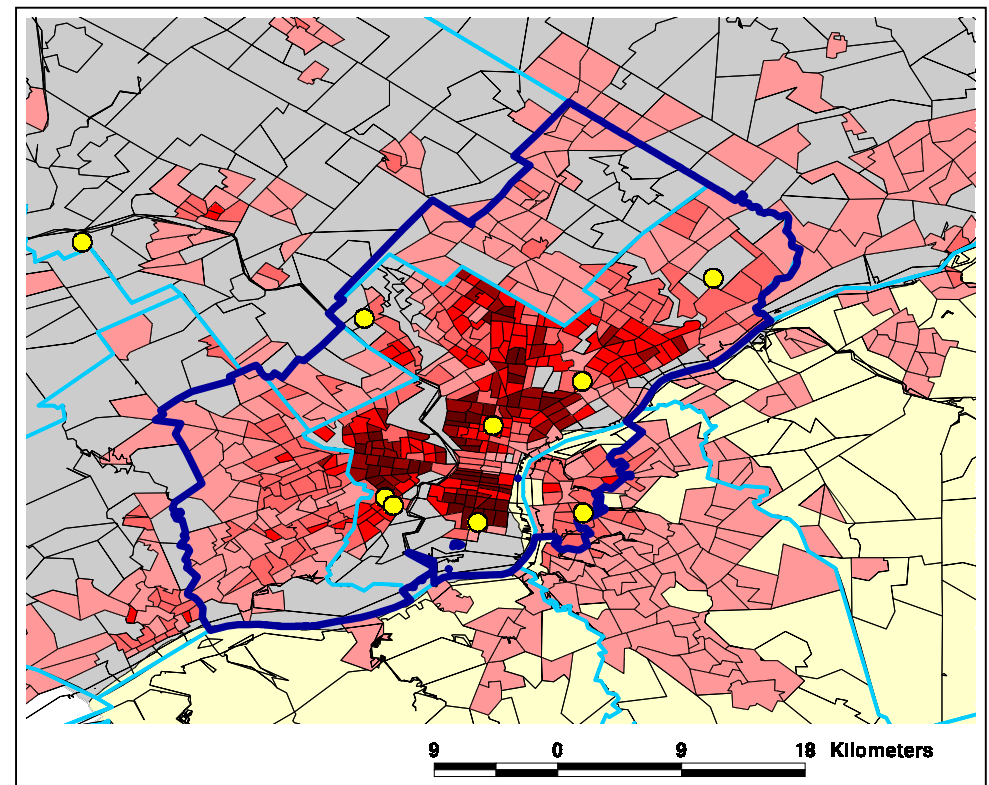
○ PM2.5 sites (Harvard MAACS)
□ Model Area
□ Counties

Exposure Modeling Methods

- Microenvironmental approach (inhalation)
  - Total exposure (E) is the time-weighted sum of exposures from all the different microenvironments in which a person spends time:

$$E = \sum_j E_j = \frac{1}{T}\left(\sum_j \overline{C}_j t_j\right)$$

where:

E_j = exposure while in microenvironment j
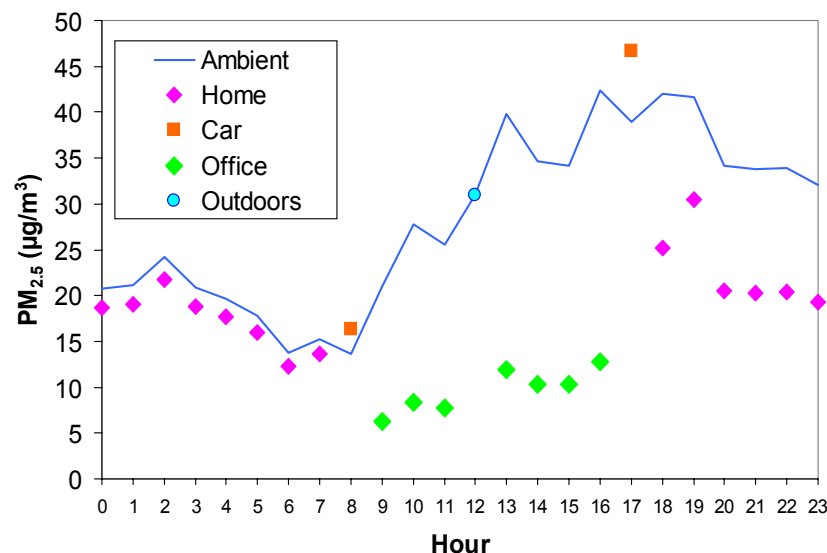
C_j = average concentration in microenvironment j

t_j = time spent in microenvironment j
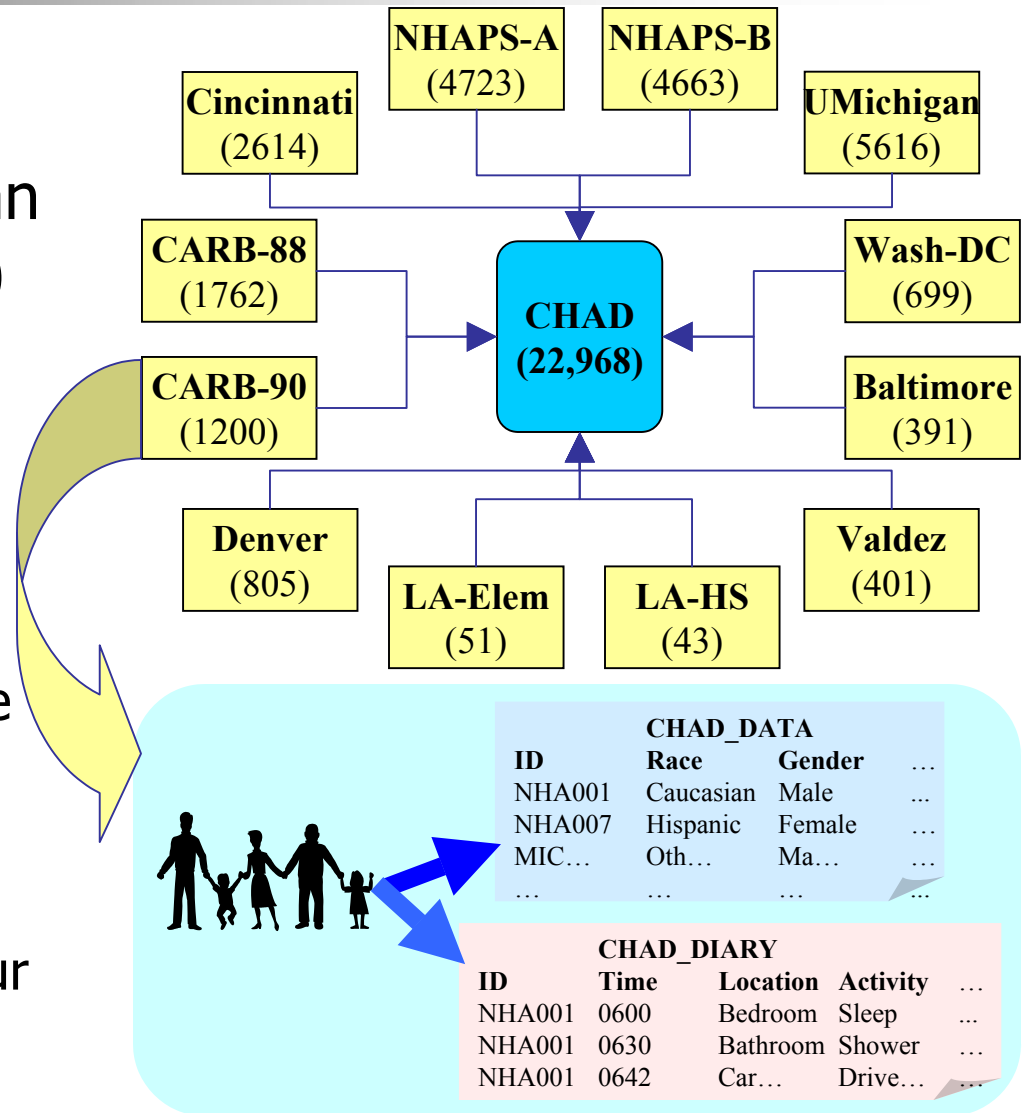
T = the sum of t_j over all j

Exposure Modeling Methods

- ## Time-series approach

  - exposures estimated sequentially through time as individuals encounter various microenvironmental concentrations

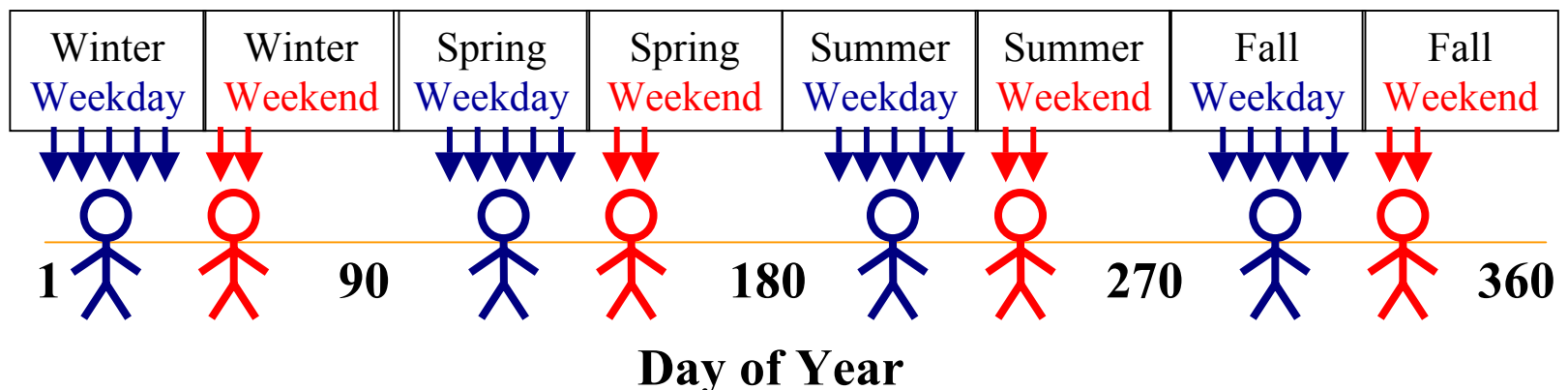 - allows for time-varying exposure/dose profile of individual

Exposure Modeling Methods

- Human activity data from EPA's Consolidated Human Activity Database (CHAD)

  - Compilation of several human activity surveys

  - Participant's demographic data (age, race, gender)

  - Diary data in standardized format (24-hours, 1 minute to 1 hour)

  - 114 location and 144 activity codes

  - Most surveys single 24-hour diary for participant

NHAPS-A (4723)	NHAPS-B (4663)
Cincinnati (2614)	UMichigan (5616)
CARB-88 (1762)	CHAD (22,968)	Wash-DC (699)
CARB-90 (1200)		Baltimore (391)
Denver (805)	LA-Elem (51)	LA-HS (43)	Valdez (401)

CHAD_DATA

ID	Race	Gender	...
NHA001	Caucasian	Male	...
NHA007	Hispanic	Female	...
MIC...	Oth...	Ma...	...
...	...	...	...

CHAD_DIARY

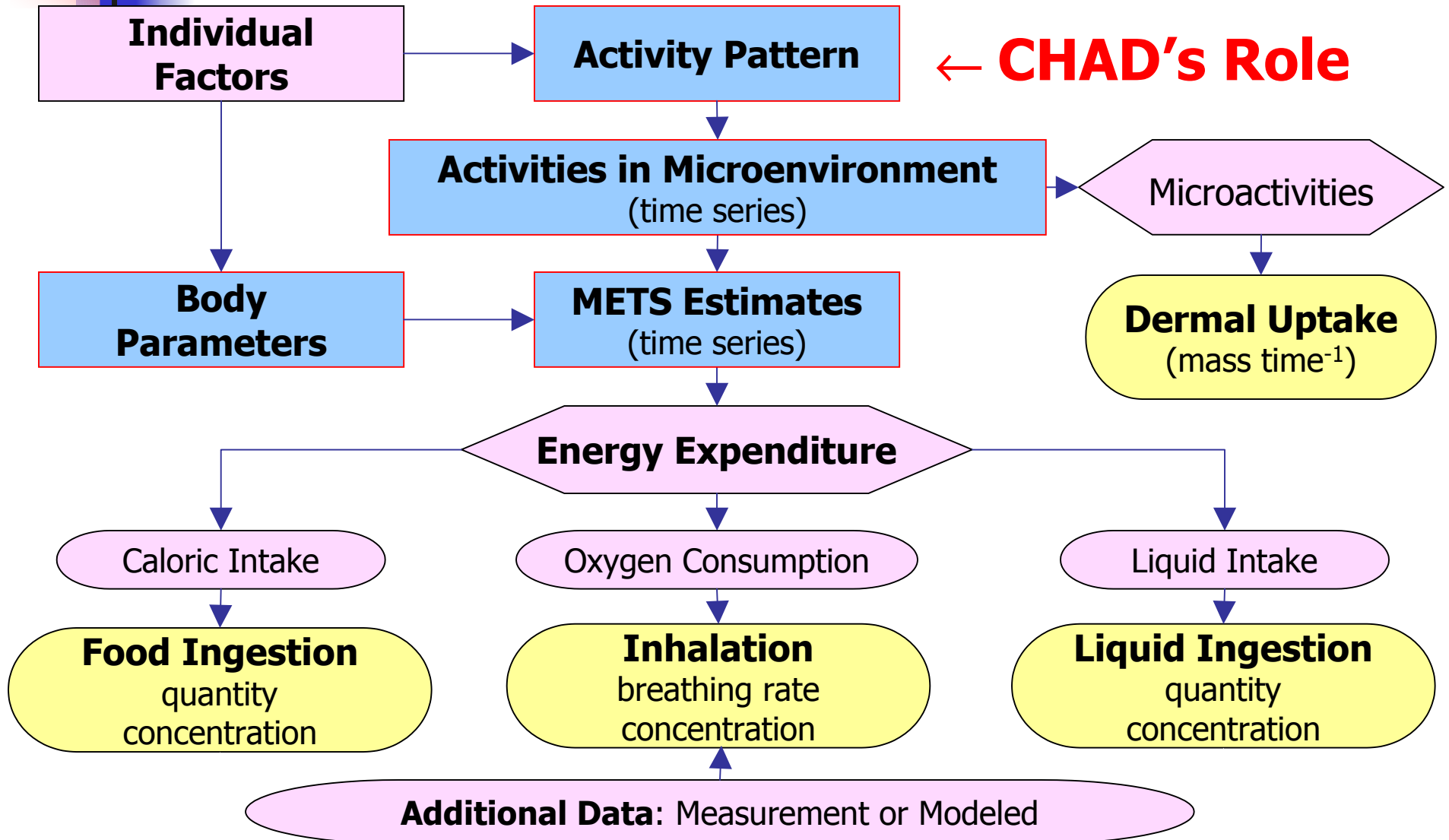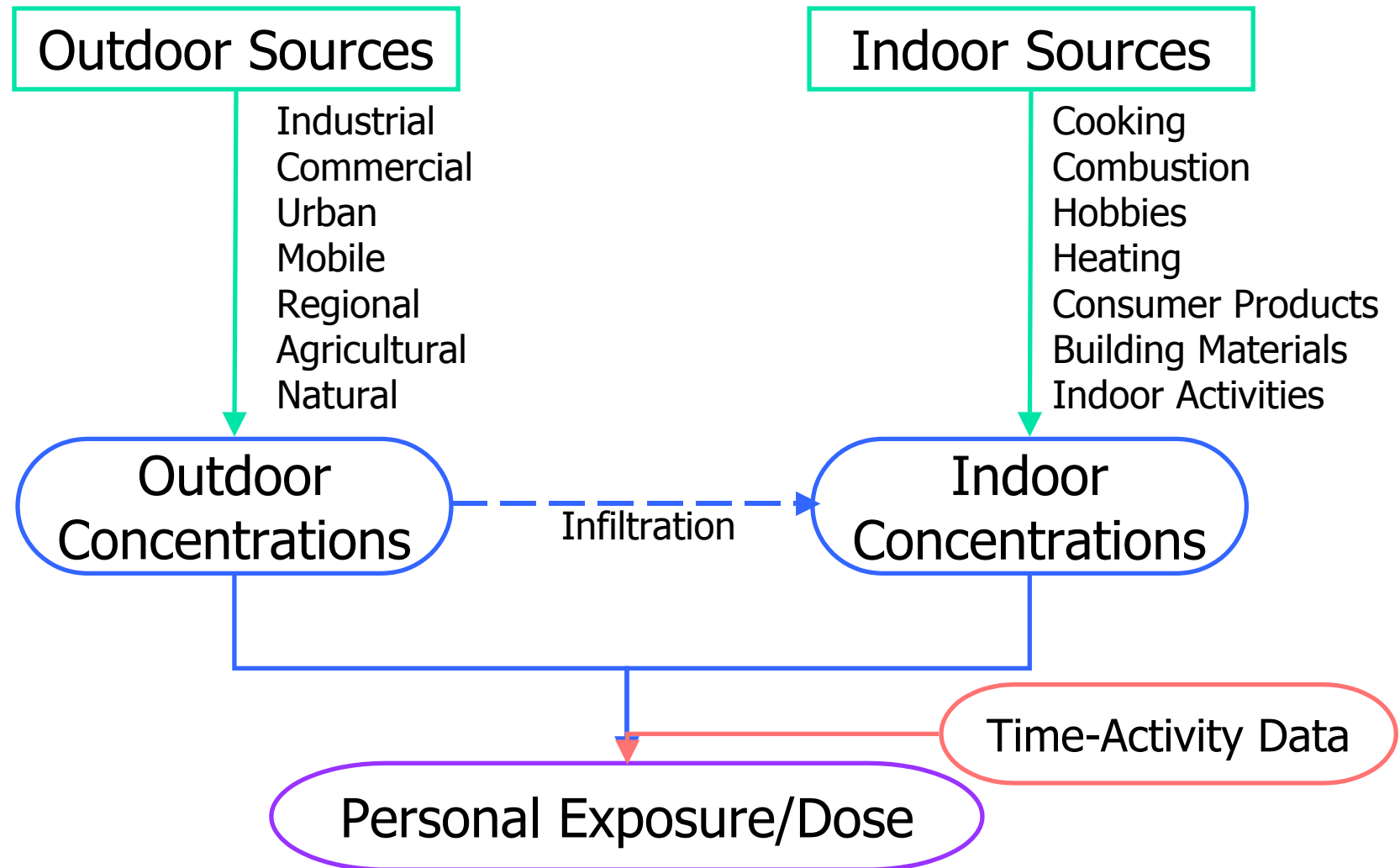| ID	Time	Location	Activity	...
NHA001	0600	Bedroom	Sleep	...
NHA001	0630	Bathroom	Shower	...
NHA001	0642	Car...	Drive...	...
...	...	...	...	

Exposure Modeling Methods

- Longitudinal activity diary constructed for each simulated individual
  - Diaries from different people grouped by similar characteristics (age, gender, employed, etc.)
  - Approach impacts intra- and inter-individual variability
    - Same activity diary every day
    - Different activity diary every day
    - Combination: same diary every weekday during a season

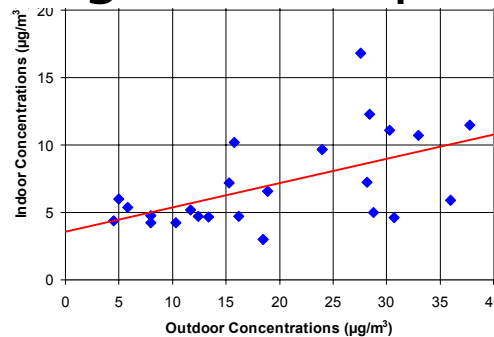| Winter Weekday	Winter Weekend	Spring Weekday	Spring Weekend	Summer Weekday	Summer Weekend	Fall Weekday	Fall Weekend

1   90   180   270   360

Day of Year

Exposure Modeling Methods

Individual Factors → **Activity Pattern**   ← **CHAD's Role**

Activities in Microenvironment (time series) → **Microactivities**

Body Parameters → **METS Estimates** (time series)

Dermal Uptake (mass time^{-1})

Energy Expenditure

Caloric Intake

Oxygen Consumption

Liquid Intake

Food Ingestion quantity concentration

Inhalation breathing rate concentration

Liquid Ingestion quantity concentration

Additional Data: Measurement or Modeled

Exposure Pathway: Inhalation

Outdoor Sources	Indoor Sources
Industrial	Cooking
Commercial	Combustion
Urban	Hobbies
Mobile	Heating
Regional	Consumer Products
Agricultural	Building Materials
Natural	Indoor Activities

Outdoor Concentrations → Infiltration → Indoor Concentrations

Personal Exposure/Dose

Time-Activity Data
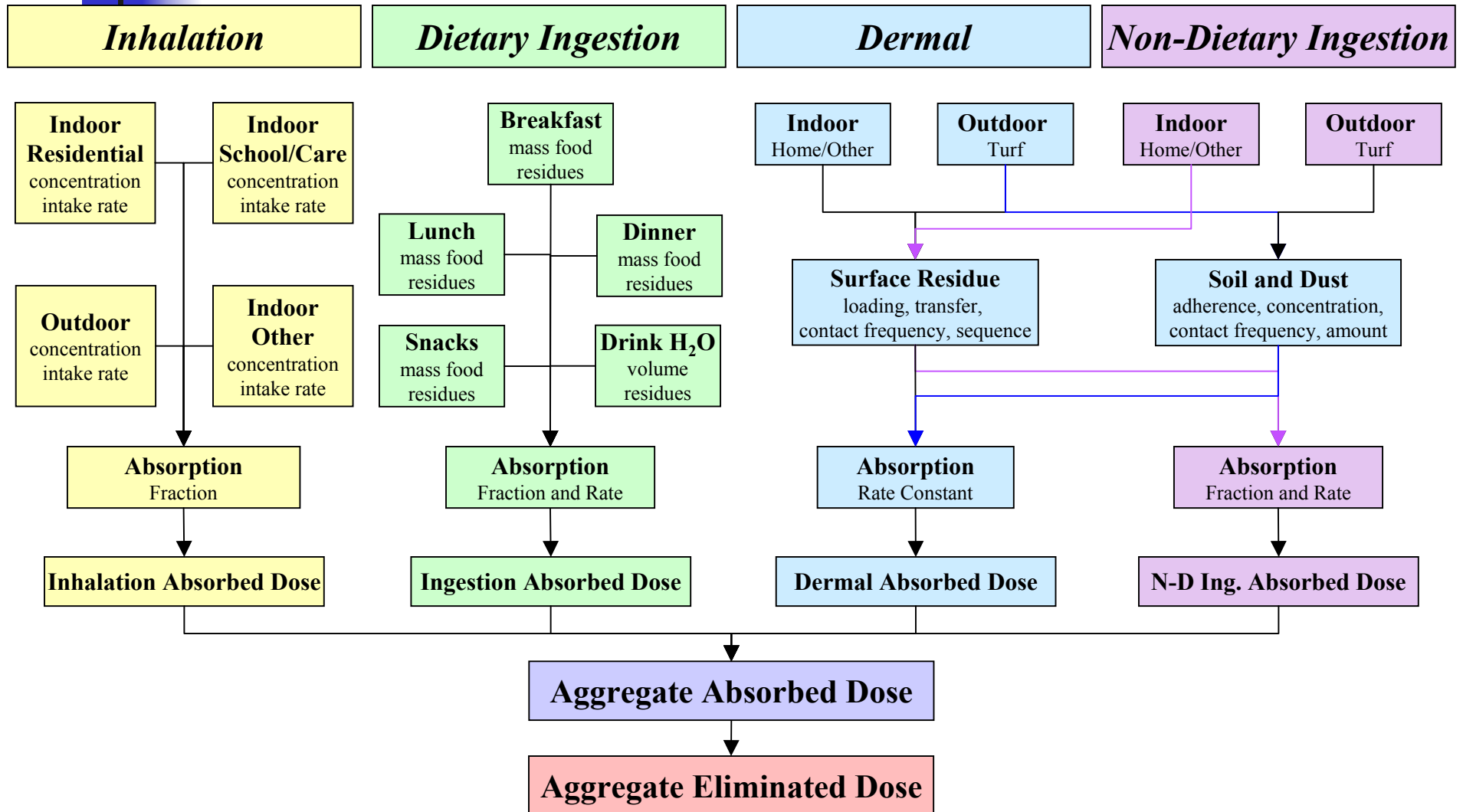
Exposure Pathways: Inhalation

- Microenvironmental concentrations
  - Indoor/outdoor ratio
  - Indoor/outdoor regression equation

  - Mass balance equation
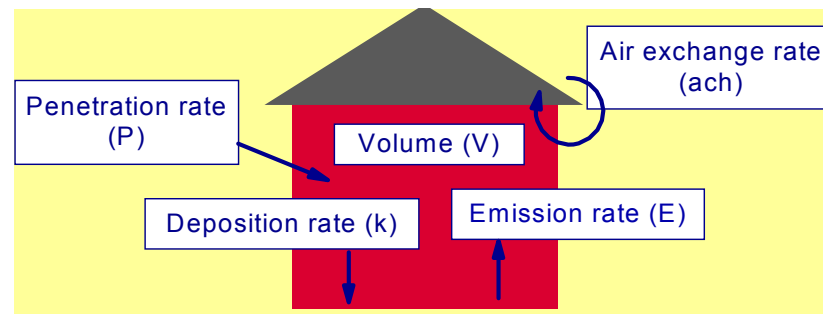
Exposure Pathways: Multimedia

Inhalation	**Dietary Ingestion**	**Dermal**	**Non-Dietary Ingestion**

Inhalation

Indoor Residential
concentration intake rate

Indoor School/Care
concentration intake rate

Outdoor
concentration intake rate

Indoor Other
concentration intake rate

Absorption
Fraction

Inhalation Absorbed Dose

Dietary Ingestion

Breakfast
mass food residues

Lunch
mass food residues

Dinner
mass food residues

Snacks
mass food residues

Drink H$_2$O
volume residues

Absorption
Fraction and Rate

Ingestion Absorbed Dose

Dermal

Indoor
Home/Other

Outdoor
Turf

Surface Residue
loading, transfer, contact frequency, sequence

Absorption
Rate Constant

Dermal Absorbed Dose

Non-Dietary Ingestion

Indoor
Home/Other

Outdoor
Turf

Soil and Dust
adherence, concentration, contact frequency, amount

Absorption
Fraction and Rate

N-D Ing. Absorbed Dose

Aggregate Absorbed Dose

Aggregate Eliminated Dose

Overview of Exposure Models

- Simple
  - HEM 2000 (Inhalation with no activity patterns)
  - HAPEM4 (Inhalation with activity patterns)
  - IEM/MPE (Multipathway tool)
- Complex
  - APEX (Inhalation with activity patterns)
  - TRIM.Expo
    - Inhalation, Ingestion
  - SHEDS
    - Inhalation, Ingestion, Dermal

Exposure Models: HEM 2000

- Human Exposure Model 2000 (HEM 2000)
  - Combines a dispersion model (ISC) with 2000 census data to predict population exposure
  - Does NOT account for human activity pattern
  - Assumes everyone lives at census block centroid for entire exposure period
  - Currently used in Residual Risk assessments as a screening tool

Exposure Models: HAPEM4

- Hazardous Air Pollutant Exposure Model Version 4 (HAPEM4)
  - Census tract resolution; cohort activity data from CHAD; pollutant specific ME factors; can also vary factors by source sector; includes background air quality; adult commuting feature; runs on PC or workstation; documentation available
  - ME factor approach for indoor penetration of outdoor pollutants with additive indoor source term (ADD)
  - Best suited for large scale exposures (national)
  - Chronic exposures

Exposure Models: HAPEM4

- Model and detailed ME report at:
  http://www.epa.gov/ttn/atw/nata/natsa3.html

- Detailed Case Study
  - Requested by SAB in NATA review
  - Run HAPEM4 for a small area in Houston
    - 500 meter AQ resolution in central city
    - 88 census tracts (2-71 AQ values per tract)
    - Sensitivity Simulations (approx 10 runs)
      - "Tweak" a selected parameter each run
      - ME (prox,pen), activity, AQ, ADD
  - Benzene and Chromium - report late 2003

Exposure Models: APEX

- Air Pollutant Exposure Model (APEX)
  - Models both criteria pollutants and air toxics at urban scale
  - Acute to chronic exposures
  - Microenvironment selection, selection of time period,
  - Ambient monitor data or values from dispersion model
  - Models individuals (instead of cohorts)
  - Sub-census tract resolution; accepts point estimates or distributions for most inputs; includes temperature variation in study area; build lifetime exposure profile
  - Mass balance or ME factor based approach
  - Programmers and users guide; runs on PC

Exposure Models: TRIM

- **Total Risk Exposure Model Component (TRIM.Expo)**
  - TRIM.Expo Inhalation Component (FY03)
    - incorporates features of APEX and HAPEM4 models
  - TRIM.Expo Ingestion Component (Late FY03)
    - developing algorithms from existing ingestion exposure models
    - creation and testing of linkages between TRIM.FaTE and the TRIM inhalation exposure module (FY03 - FY04)
    - peer review (as appropriate) (FY04)
  - Graphical user interface (FY03)
    - java based to run on PC, Workstation, via Internet

Exposure Models: HAPEM5

- Hazardous Air Pollutant Exposure Model V5 (HAPEM5) - Late 2003
  - Improvements to HAPEM4 based on SAB comments:
    - include ME factor distributions
    - improved treatment of longitudinal activity patterns
    - developing data for indoor air component (ADD)
    - Modify for 2000 Census
    - Children commuting algorithms
    - Comparison with personal monitoring

Exposure Models: SHEDS

- Stochastic Human Exposure and Dose Simulation (SHEDS)
    - Incorporates both variability and uncertainty in predicted exposure distribution using 2-stage Monte Carlo sampling technique
    - Approach used for particulate matter ($PM_{2.5}$) and for pesticides (chlorpyrifos)
    - Currently developing SHEDS for air toxics that combines features from SHEDS-PM and SHEDS-Pesticides
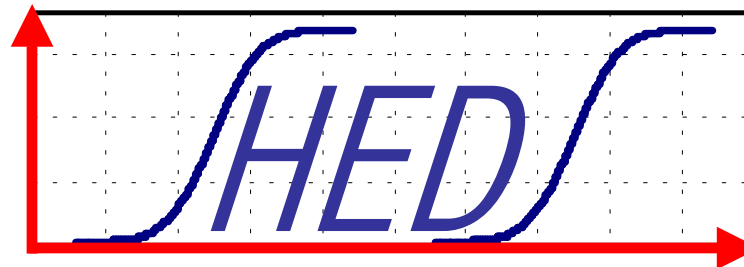
Exposure Models: SHEDS

Variability

- temporal, spatial, or inter-individual differences in the value of an input
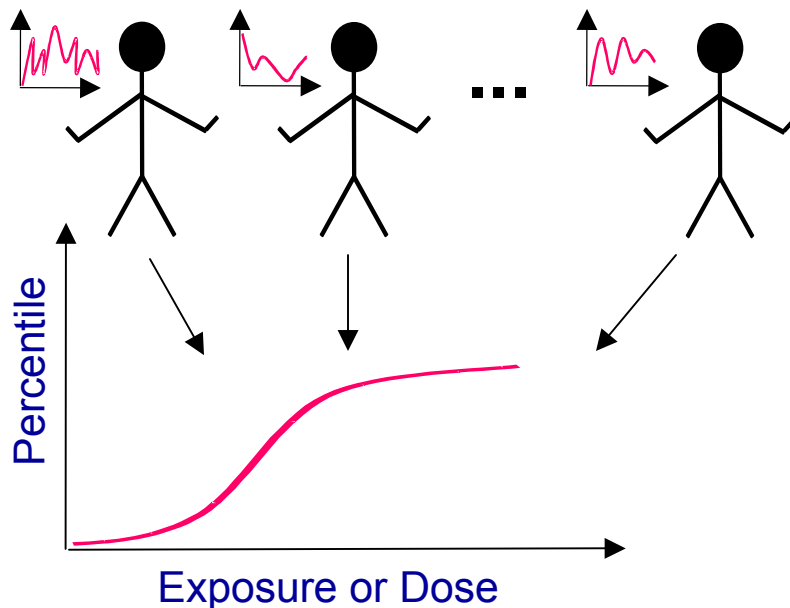
Uncertainty

- measure of the incompleteness of knowledge/information
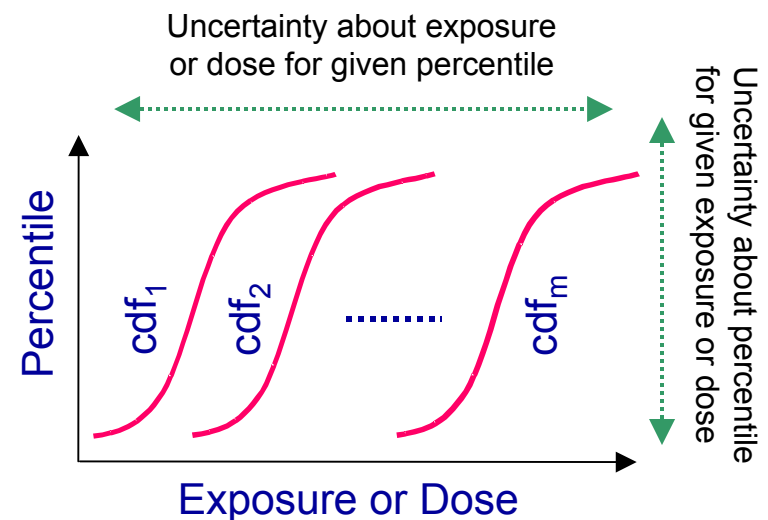
Exposure Models: SHEDS

- **SHEDS-Air Toxics (ATOX)**
  - Strategy for model development
    - Focus on mobile source air toxics initially (benzene)
    - Followed by multimedia pollutants (arsenic)
    - Consider indoor sources (aldehydes)
  - Initiating development with benzene case study
  - Prototype version 1.0 to be completed by FY03
    - Aggregate (multipathway, multimedia) exposure model
    - Longitudinal and cross-sectional options
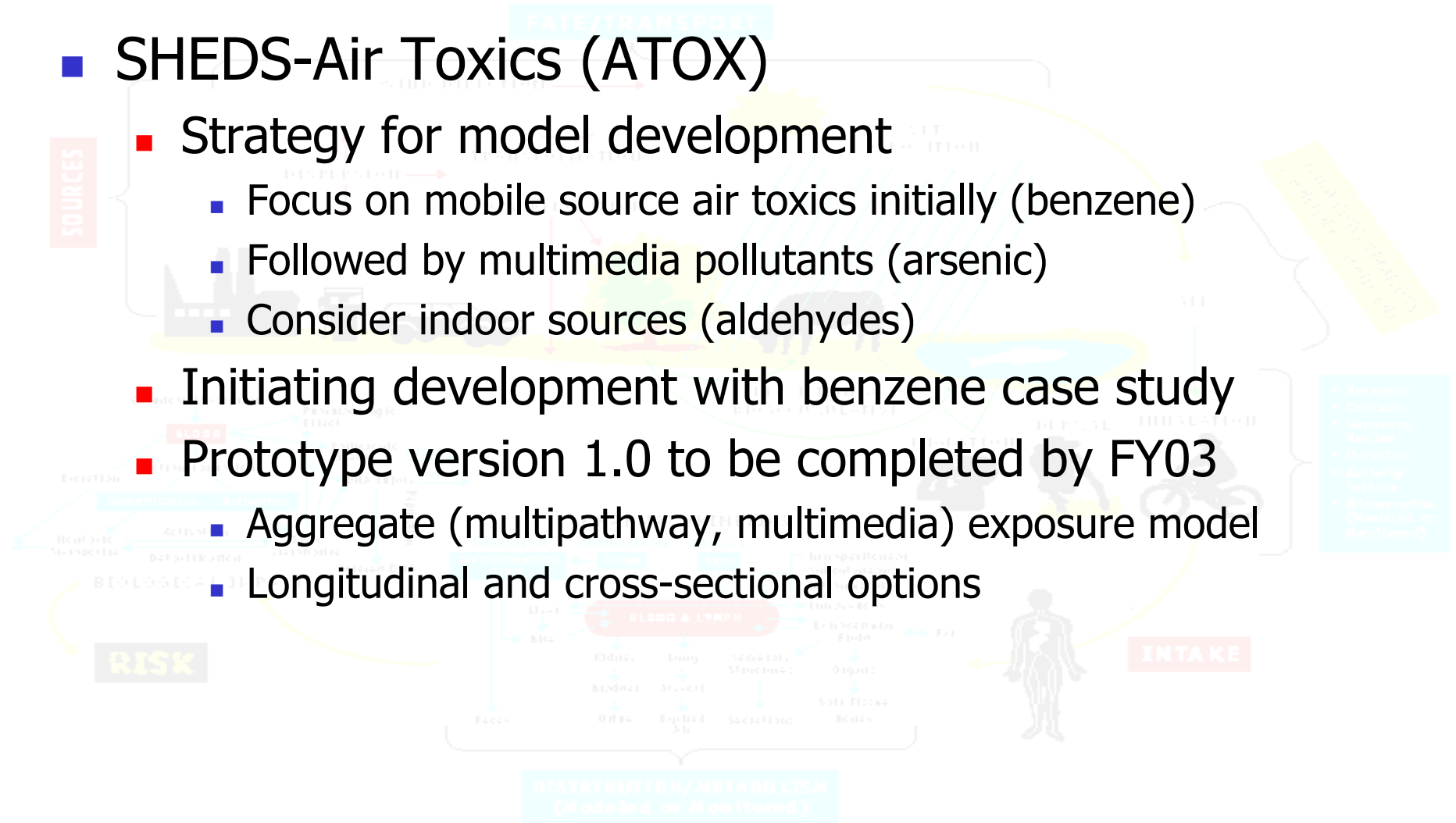
SHEDS-ATOX: Benzene

- Focus on developing/improving algorithms to estimate exposure to mobile source air toxics
  - Review of current studies to gather data for critical exposure microenvironments and influential factors
  - Commuting Algorithm
    - provides probabilities for work census tract, home census tract and "other" census tract locations.
    - national commuting flow database developed for HAPEM and APEX3 is utilized
      - based on 1994 commuting flow database
      - mapped onto census tracts for Census 2000
  - Establish Consistencies
    - initiate a correlation between CHAD diary travel time and census tract distance in commute
    - consider workers, students, and other classification in longitudinal diary construction

SHEDS-ATOX: Benzene

- **In-vehicle exposures**
    - time-specific local exposures estimated
        - based on time modified (TOD, DOW, MOY) roadway traffic densities (AADT) and hourly ambient concentrations.

- **Refueling exposure**
    - seasonal and fuel-type component
    - to consider travel time for individual frequency interval

- **Garages**
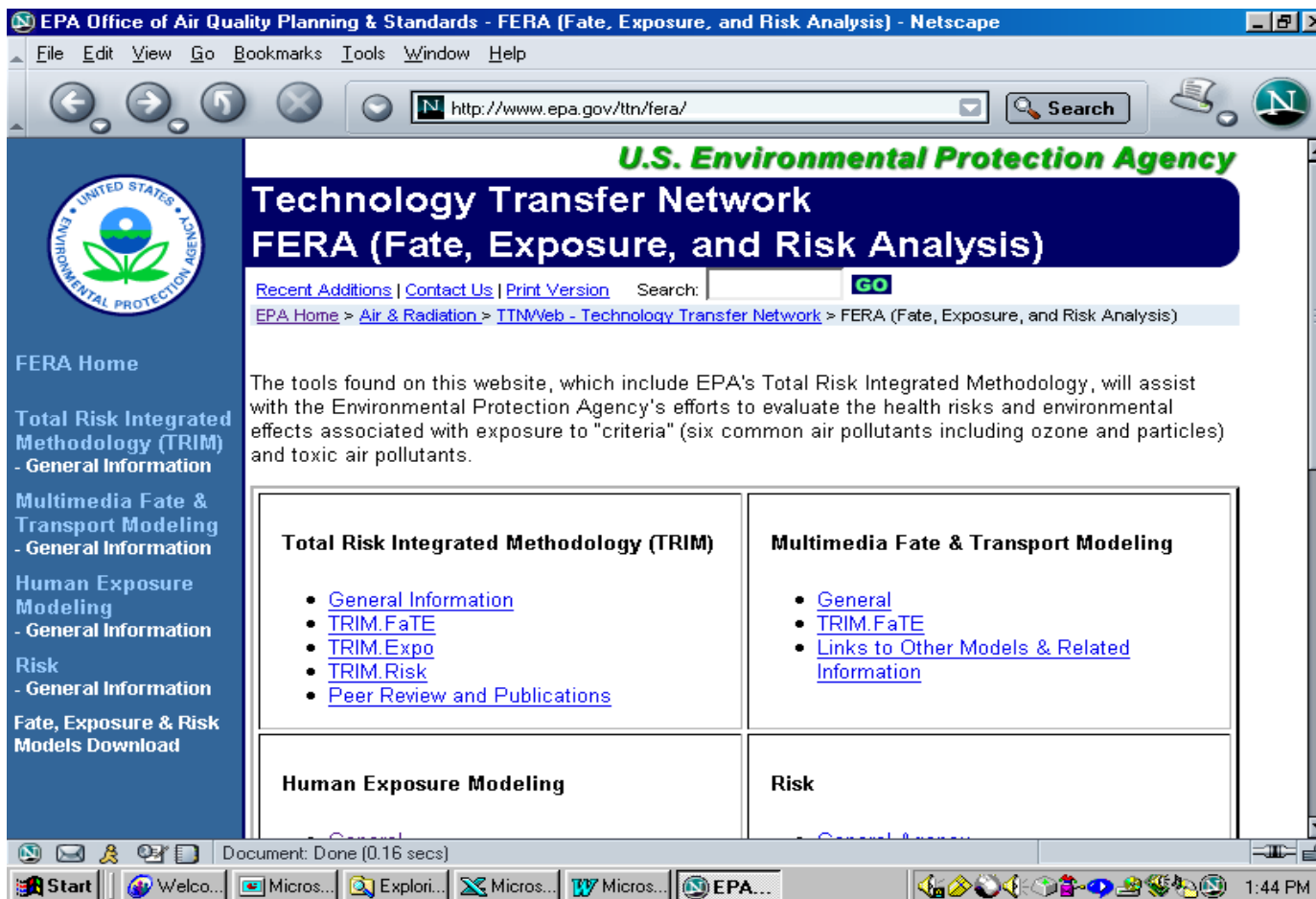   - both in-garage exposure and infiltration into house (attached garages)

Exposure Models: Comparison

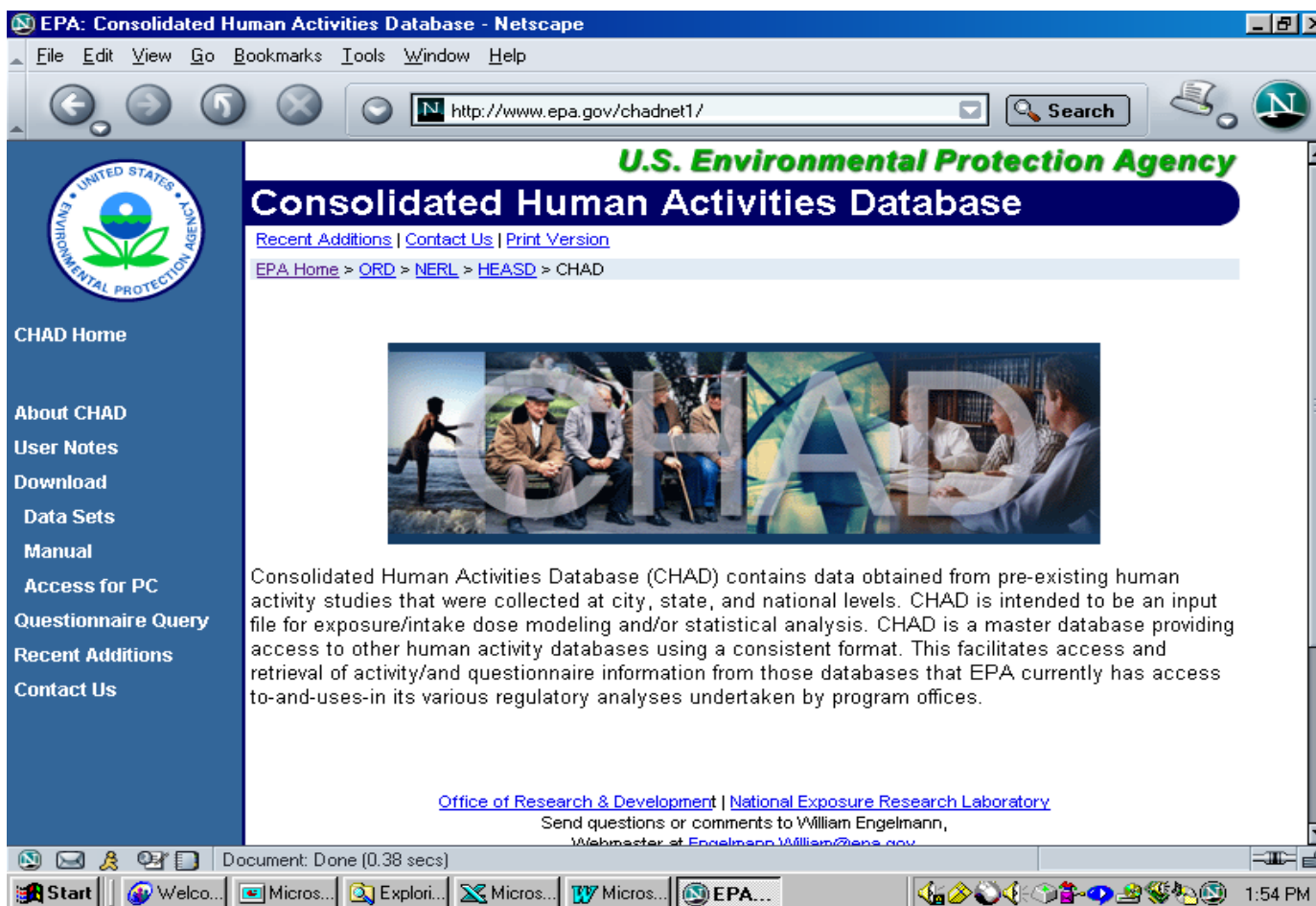|	Spatial Scale	Time Scale	Pathway	Activity Data Used	Inputs
HEM	Local to source	Lifetime (chronic)	Inhalation	No	ISC conc., Census
HAPEM	National → Urban	One year (chronic)	Inhalation	Yes (cohorts)	Census, ME factor
APEX/ TRIM	Urban	One year (acute and chronic)	Inhalation/ Inhalation, Ingestion	Yes (individuals)	Census, Point → Distributions (variability)
SHEDS	Urban	One year (acute and chronic)	Inhalation, Ingestion, Dermal	Yes (individuals)	Census, Point → Distributions (variability, uncertainty)

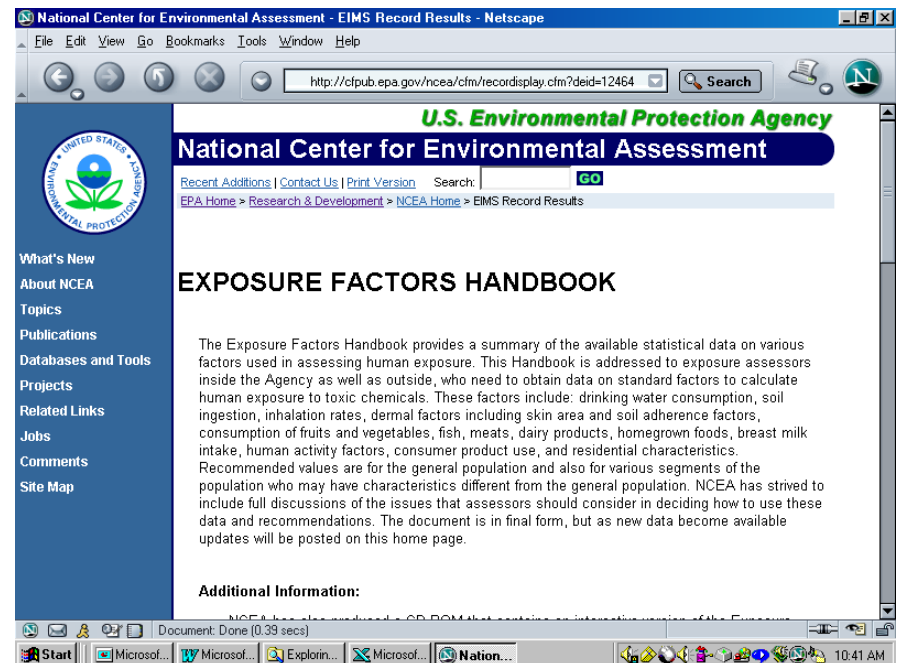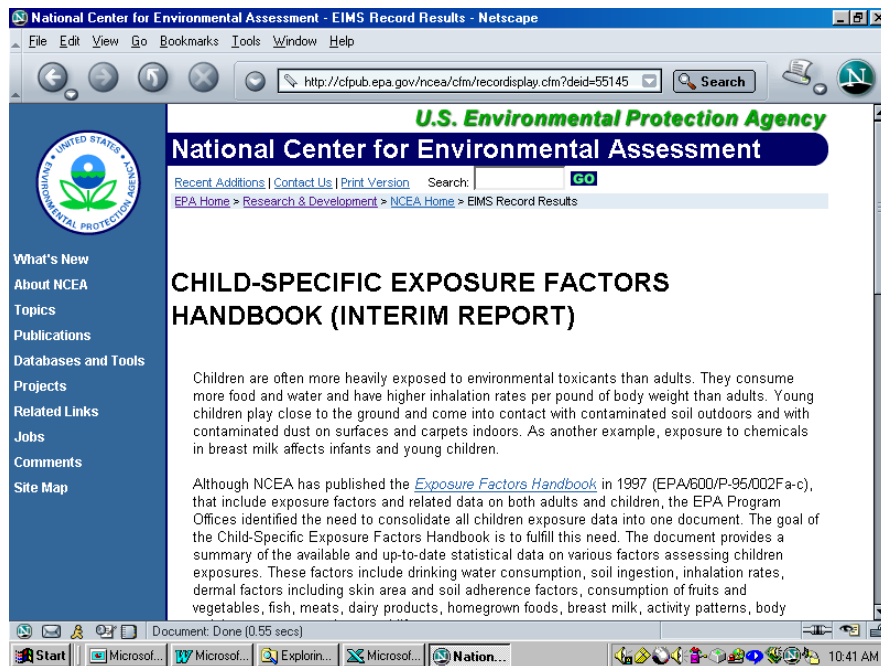# Modeling Tools: TTN FERA Website

- http://www.epa.gov/ttn/fera/

Modeling Tools: CHAD Website

- http://www.epa.gov/chadnet1/

Modeling Tools: NCEA EFH websites

- http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=55145
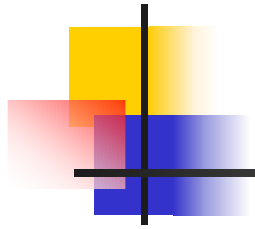- http://cfpub1.epa.gov/ncea/cfm/recordisplay.cfm?deid=12464

Questions?

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    919-541-4344